Performance Analysis of Adaptive Beamforming at Receiver Side by using LMS and RLS Algorithms

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Abstract:- The Least Mean Squares (LMS) algorithm is an important member of the family of stochastic gradient algorithms. A significant feature of the LMS algorithm is its simplicity. The recursive least squares (RLS) algorithm recursively finds the filter coefficients for minimizing linear least squares cost function. Smart antenna generally refers to any antenna array. Beamforming is a signal processing technique used in sensor arrays for directional signal transmission or reception. This spatial selectivity is achieved by using adaptive or fixed receive/transmit beam patterns. The improvement compared with an omnidirectional reception/transmission is known as the receive/transmit gain (or loss). In this study, fixed weight beamforming basics and maximum signal to interference ratio are given. The theoretical information of adaptive beamforming, LMS (Least Mean Square) and RLS (Recursive Mean Squares) algorithms are explained. Adaptive beamforming in recieve antenna is simulated by using LMS and RLS algorithms. Simulation results are discussed and explained.

Index Terms—LMS, RLS, Beamforming, Smart Antennas.

I. INTRODUCTION

The LMS algorithm is an important member of the family of stochastic gradient algorithms. The term 'stochastic gradient' is intended to distinguish the LMS algorithm from the method of steepest descent which uses a deterministic gradient in a recursive computation of the Wiener filter for stochastic inputs [1]. A significant features of the LMS algorithm are its simplicity and robust performance against different channel conditions [2]. However, it has slow convergence and does not have robustness for high channel changes [3]. The LMS algorithm is a linear adaptive filtering algorithm, which in general consists of two basic processes [4]:

A filtering process, which involves computing the output of a linear filter in response to an input signal and generating an estimation error by comparing this output with a desired response. An adaptive process which involves the automatic adjustment of the parameters of the filter in accordance with the estimation error. The LMS algorithm performs the following operations to update the coefficients of an adaptive filter:

1- Calculates the output signal y(n) from the adaptive filter.
2- Calculates the error signal e(n) by using the following equation:
$$e(n) = d(n) - y(n)$$
3- Updates the filter coefficients by using the following equation:
$$\widehat{w}(n+1) = \widehat{w}(n) + \mu e(n)\hat{u}(n)$$

The RLS algorithm recursively finds the filter coefficients that minimize a weighted linear least squares cost function relating to the input signals. It has fast convergence and it considers channel changes but it comprises complex processes and it is costly in engineering point of view [5]. In contrast to other algorithms such as LMS that aim to reduce the mean square error. In the derivation of the RLS, the input signals are considered deterministic on the other hand in LMS they are considered stochastic [6]. All necessary equations for RLS algorithm are given below:

1- $e(n) = d(n) - u(n)^T w(n-1)$
2- $k(n) = \frac{\lambda^{-1}P(n-1)u(n)}{1+\lambda^{-1}u^T(n)P(n-1)u(n)}$
3- $\alpha(n) = d(n) - u(n)^T w(n-1)$
4- $w(n) = w(n-1) + k(n)\alpha(n)$
5- $P(n) = \lambda^{-1}P(n-1) - \lambda^{-1}k(n)u^T(n)P(n-1)$

Smart antenna generally refers to any antenna array terminated in sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals [7].

Smart antennas generally encompass both switched beam and beam-formed adaptive systems. Switched beam systems have several available fixed beam patterns. A decision is made as to which beam to access, at any given point in time, based upon the requirements of the system. Beamformed adaptive systems allow the antenna to ster the beam to any direction of interest while simultaneously canceling interfering signals. The smart antenna concept is opposed to the fixed beam "dumb antenna," which does not attempt to adapt its radiation pattern to an ever-changing electromagnetic environment. In the past, smart antennas have alternatively been labeled adaptive arrays or digital beamforming arrays. This new terminology reflects our penchant for "smart" technologies and more accurately identifies an adaptive array that is controlled by sophisticated signal processing [8].

The rapid growth in demand for smart antennas is filled by two major reasons. First, the technology for high speed analog-to-digital converters (ADC) and high speed digital signal processing is developing at an alarming rate. Early smart antennas, or adaptive arrays, were limited in their capabilities because adaptive algorithms were usually implemented in analog hardware. With the growth of ADC and digital signal processing (DSP); what was once performed in hardware can now be performed digitally and quickly. ADCs, which have resolutions that range from 8 to 24 bits, and sampling rates approaching 20 Gigasamples per second (GSa/s), are now a reality. In time, superconducting data converters will be able to sample data at rates up to 100 GSa/s. This makes the direct digitization of most radio frequency (RF) signals possible in many wireless applications. At the very least, ADC can be applied to IF frequencies in higher RF frequency applications. This allows most of the signal processing to be defined in software near the front end of the receiver. In addition, DSP can be implemented with high speed parallel processing using field programmable gate arrays (FPGA). Current commercially available FPGAs have speeds of up to 256 BMACS. Thus, the benefits of smart antenna integration will only flourish, given the exponential growth in the enabling digital technology continues. Second, the global demand for all forms of wireless communication and sensing continues to grow at a rapid rate. Smart antennas are the practical realization of the subject of adaptive array signal processing and have a wide range of interesting applications. These applications include, but are not limited to, the following: mobile wireless communications, software-defined radio, wireless local area networks (WLAN), wireless local loops (WLL), mobile Internet, wireless metropolitan area networks (WMAN), satellite based personal communications services, radar , ubiquitous radar , many forms of remote sensing, mobile ad hoc networks (MANET), high data rate communications, satellite communications, multiple-in-multiple-out (MIMO) systems, wireless sensor networks (WSNs) and waveform diversity systems. The rapid growth in telecommunications alone is convenient to justify the incorporation of smart antennas to enable higher system capacities and data rates.

Smart antennas have numerous important benefits in wireless applications as well as in sensors such as radar. In the hotspot of mobile wireless applications, smart antennas can provide higher system capacities by directing narrow beams toward the users of interest, while nulling other users not of interest. This allows for higher signal-to-interference ratios, lower power levels, and permits greater frequency reuse within the same cell. This concept is called space division multiple access (SDMA). In the United States, most base stations sectorize each cell into three 120 degrees swaths. This allows the system capacity to potentially triple within a single cell because users in each of the three sectors can share the same spectral resources. Most base stations can be modified to include smart antennas within each sector. This further subdivision enables the use of lower power levels, and provides for even higher system capacities and greater bandwidths. Another benefit of smart antennas is that the unhealtful effects of multipath can be eased. A constant modulus algorithm, which controls the smart antenna, can be implemented in order to null multipath signals. This will dramatically reduce fading in the received signal. Higher data rates can be realized because smart antennas can simultaneously reduce both co-channel interference and multipath fading. Multipath reduction not only benefits mobile communications but also applies to many applications of radar systems. Smart antennas can be used to enhance direction-finding (DF) techniques by more accurately finding angles-of-arrival (AOA). A vast array of spectral estimation techniques can be incorporated, which are able to isolate the AOA with an angular precision that exceeds the resolution of the array. The accurate estimation of AOA is especially beneficial in radar systems for imaging objects or accurately tracking moving objects. Smart antennas also play a role in MIMO communications systems and in waveform diverse MIMO radar systems. Since diverse waveforms are transmitted from each element in the transmit array and are combined at the receive array, smart antennas will play a role in modifying radiation patterns in order to best capitalize on the presence of multipath. With MIMO radar, the smart antenna can exploit the independence between the various signals at each array element in order to use target blooming for improved performance, to improve array resolution, and to mitigate clutter. In summary, some of the numerous potential benefits of smart antennas are listed below.

- Improved system capacities
- Higher permissible signal bandwidths
- Space division multiple access (SDMA)
- Higher signal-to-interference ratios
- Increased frequency reuse
- Sidelobe canceling or null steering
- Multipath mitigation
- Constant modulus restoration to phase modulated signals
- Blind adaptation
- Improved angle-of-arrival estimation and direction finding
- Instantaneous tracking of moving sources
- Reduced speckle in radar imaging
- Clutter suppression
- Increased degrees of freedom
- Improved array resolution
- MIMO compatibility in both communications and radar

II) BEAMFORMING

Beamforming is a signal processing technique used in sensor arrays for directional signal transmission or reception. This spatial selectivity is obtained by using adaptive or fixed receive/transmit beampatterns. The improvement compared

with an omnidirectional reception/transmission is known as the receive/transmit gain (or loss).

Beamforming takes advantage of interference to change the directionality of the array. When transmitting, a beamformer controls the phase and relative amplitude of the signal at each transmitter, in order to create a pattern of constructive and destructive interference in the wavefront. When receiving, information from different sensors is combined in such a way that the expected pattern of radiation is preferentially observed. With narrow-band systems the time delay is equivalent to a "phase shift", so in this case the array of antennas, each one shifted a slightly different amount, is called a phased array. A narrow band system, typical of radars, is one where the bandwidth is only a small fraction of the centre frequency. With wide band systems this approximation no longer holds, which is typical in sonars.

In the receive beamformer the signal from each antenna may be amplified by a different "weight." Different weighting patterns (e.g., Dolph-Chebyshev) can be used to achieve the desired sensitivity patterns. A main lobe is produced together with nulls and sidelobes. As well as controlling the main lobe width (the beam) and the sidelobe levels, the position of a null can be controlled. This is useful to ignore noise or jammers in one particular direction, while listening for events in other directions. A similar result can be obtained on transmission for the full mathematics on directing beams using amplitude and phase shifts, see the mathematical section in phased array.

Beamforming techniques can be broadly divided into two categories:

1- Conventional (fixed or switched beam) beamformers
2- Adaptive beamformers or adaptive arrays
2.1- Desired signal maximization mode
2.2- Interference signal minimization or cancellation mode

Conventional beamformers use a fixed set of weightings and time-delays (or phasings) to combine the signals from the sensors in the array, primarily using only information about the location of the sensors in space and the wave directions of interest. In contrast, adaptive beamforming techniques, generally combine this information with properties of the signals actually received by the array, typically to improve rejection of unwanted signals from other directions. This process may be carried out in the time or frequency domains [9].

As the name indicates, an adaptive beamformer is able to adapt automatically its response to different situations. Some criterion has to be set up to allow the adaption to proceed such as minimizing the total noise output. Because of the variation of noise with frequency, in wide band systems it may be desirable to carry out the process in the frequency domain.

For fixed weight beamforming basics, one criterion which can be applied to enhancing the received signal and minimizing the interfering signals is based upon maximizing the SIR. It is heuristic that if all interference can be canceled by placing nulls at their angles of arrival, the SIR will be automatically maximized.

Adaptive Beamforming is a technique in which an array of antennas is utilized to obtain maximum reception in a specified direction by estimating the signal arrival from a desired direction (in the existence of noise) while signals of the same frequency from other directions are denied. This is achieved by varying the weights of each of the sensors (antennas) used in the array. It basically uses the idea that, though the signals spreading from different transmitters occupy the same frequency channel, they still arrive from different directions. This spatial separation is exploited to separate the desired signal from the interfering signals. In adaptive beamforming the optimum weights are iteratively computed using complex algorithms based upon different criteria.

III) PROBLEM STATEMENTS

In first problem, adaptive beamformers are simulated by using LMS algorithm in MATLAB. It is proposed to cancel the interferer signal. The eight array weights for 100 iterations are calculated. The resulting weights magnitude vs iteration number figures are plotted. The desired signal and the mean square error of the array output are also plotted.

Finally, adaptive beamformer simulations are also obtained by using RLS algorithm. The same steps in problem two are repeated for RLS simulations.

IV) RESULTS AND ANALYSIS

An $M = 8$ element array with spacing $\lambda = 0.5$ has a received signal arriving at the angle $\theta_0 = 30$ degrees an interferer at $\theta_1 = -60$ degrees. MATLAB is used to write an LMS routine to solve for the desired weights. LMS is used to solve for the optimum array weights. The initial array weights are assumed that they are all zero. Results are obtained for 100 iterations.

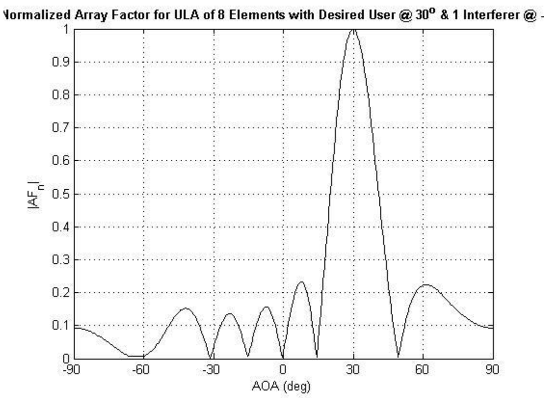

Figure 1: Array factor in LMS algorithm

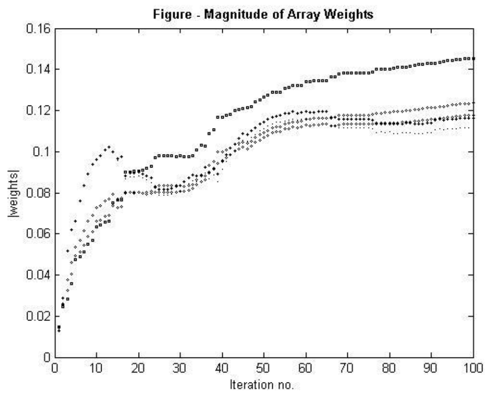

Figure 2: Magnitude of Array Weights in LMS

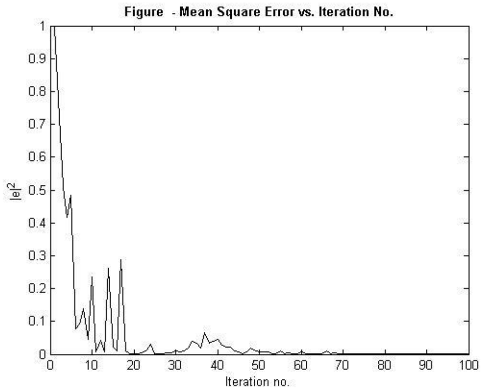

Figure 3: Mean Square Error in LMS

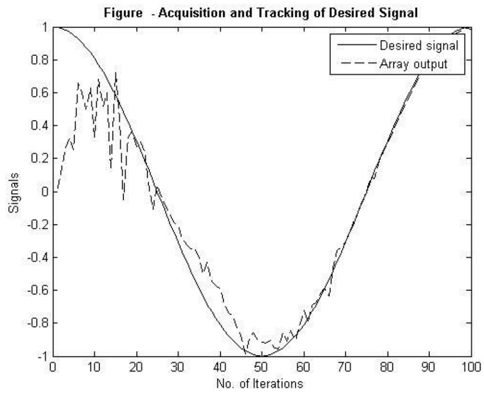

Figure 4: Acquisitian and Tracking of Desired Signal in LMS

Figure 1 shows the final weighted array which has a peak at the desired direction of 30 degrees and a null at the interfering direction of -60 degrees. Figure 3 shows the resulting mean square error which converges to near zero after 60 iterations. Figure 4 shows how the array output acquires and tracks the desired signal after about 60 iterations.

An $M = 8$ element array with spacing $\lambda = 0.5$ has a received signal arriving at the angle $\theta_0 = 30$ degrees an interferer at $\theta_1 = -60$ degrees. MATLAB is used to write an RLS routine to solve for the desired weights. RLS is used to solve for the optimum array weights. The initial array weights are assumed that they are all zero. Results are obtained for 100 iterations.

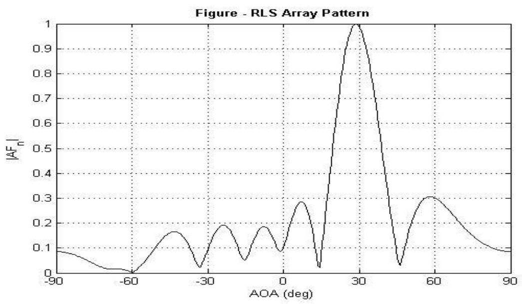

Figure 5: Array factor in RLS algorithm

Figure 5 shows the final weighted array which has a peak at the desired direction of 30 degrees and a null at the interfering direction of -60 degrees

V) CONCLUSIONS

In this study the performance analysis of bemforming by using LMS and RLS algorithms is presented. The theoretical informations of LMS and RLS are given. The development and benefits of smart antennas are discussed. The beamforming techniques are also explained. Maximum signal to interference ratio is used for beamforming simulations in Matlab. LMS and RLS algorithms are used and their results are separately obtained. Simulation results are explained. Further investigations on this topic could take several directions. Smooth beamforming for OFDM, Distributed Downlink Beamforming With Cooperative Base Stations, Optimality of Beamforming in Fading MIMO Multiple Access Channels, Combining Beamforming and Space-Time Coding Using Quantized Feedback can be studied for future researches. As a result, RLS provides better convergence and performance than LMS, however it is more complex than LMS and brings additional computational costs.

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